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SEMI-ANNUAL REPORT
1 September 1963 to 29 February 1964
Receiver Techniques and Detectors
for Use at Millimeter and Submillimeter
Wave Lengths

Grant Number NsG-74-60

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Prepared for:
National Aeronautics and Space Administration
Washington 25, D.C.

Department of ELECTRICAL ENGINEERING

THE OHIO STATE UNIVERSITY
RESEARCH FOUNDATION
Columbus, Ohio

RC#1

NOTICES

REPORT
by
THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION
COLUMBUS, OHIO 43214

Sponsor	National Aeronautics and Space Administration 1520 H Street Northwest Washington 25, D.C.
Grant Number	NsG-74-60
Investigation of	Receiver Techniques and Detectors for Use at Millimeter and Submillimeter Wave Lengths
Subject of Report	Semi-Annual Report 1 September 1963 to 29 February 1964
Submitted by	Antenna Laboratory Department of Electrical Engineering
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SEMI-ANNUAL REPORT

I. INTRODUCTION

The purpose of the present research program is to investigate various detection, generation, and receiver techniques, both conventional and non-conventional, in the millimeter and submillimeter wavelength regions. This report summarizes the research results in the grant period from September 1, 1963, to February 29, 1964, and outlines briefly the research activities planned for the period from March 1, 1964, to August 31, 1965.

II. RESEARCH RESULTS FROM SEPTEMBER 1, 1963 TO FEBRUARY 29, 1964

Although most of our effort during this period has been on the development of a submillimeter radiometer, additional work carried out in this period includes an investigation of a carbon bolometer as a detector, and an attempt to cool rare earth crystal samples to liquid helium temperatures in order to study the absorption spectra of rare earth ions.

A. The Submillimeter Radiometer

The submillimeter radiometer analyzed in Reports 1093-9 and 1093-15 and described in Reports 1093-14 and 1093-18 has been completed. Both the aperiodic and periodic modes of operation have been tested with the Golay cell detector. Many measurements have been made to study the characteristics of the instrument in its aperiodic mode. The instrument is currently used with the coeleostat of The Ohio State University in an attempt to utilize the aperiodic mode of operation to measure the solar and lunar spectra on cold winter days.

Figure 1 shows the roof-top arrangement of the coeleostat mirrors. Figure 2 shows the optics which are used to couple the interferometric submillimeter receiver to the coeleostat. Figure 3 is a typical spectral density plot obtained as a result of computer processing the data obtained from an aperiodic mode test.

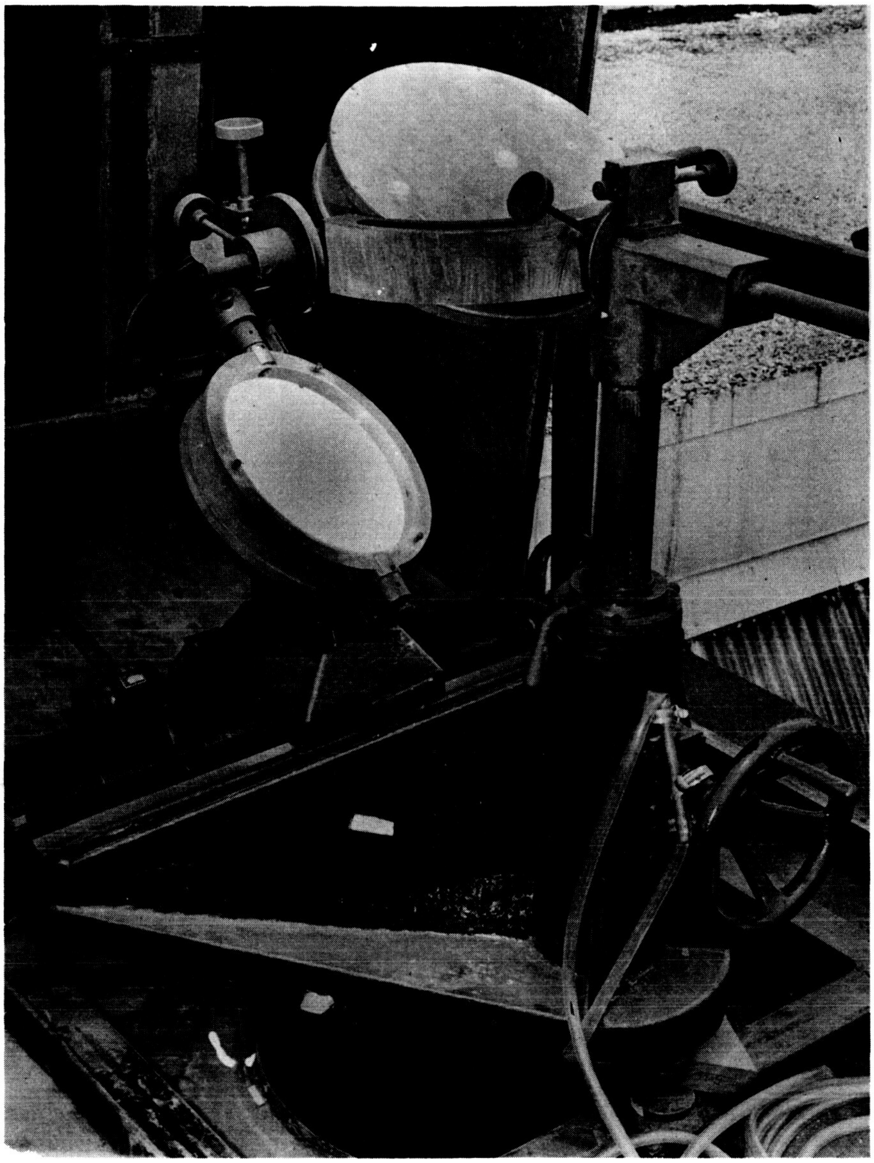

Fig. 1. "The O.S.U. Coeleostat". The upper mirrors of the coeleostat which is being used to make sky, solar, and lunar radiation measurements. This instrument is located at The Ohio State University Research Foundation building just west of Columbus, Ohio. The lower mirror is mounted on a polar axis and is driven at one revolution per 48 hours by an electric motor. The radiation is reflected into the upper mirror which reflects it down a vertical shaft onto a 45° plane mirror which reflect it horizontally into the instrument location.

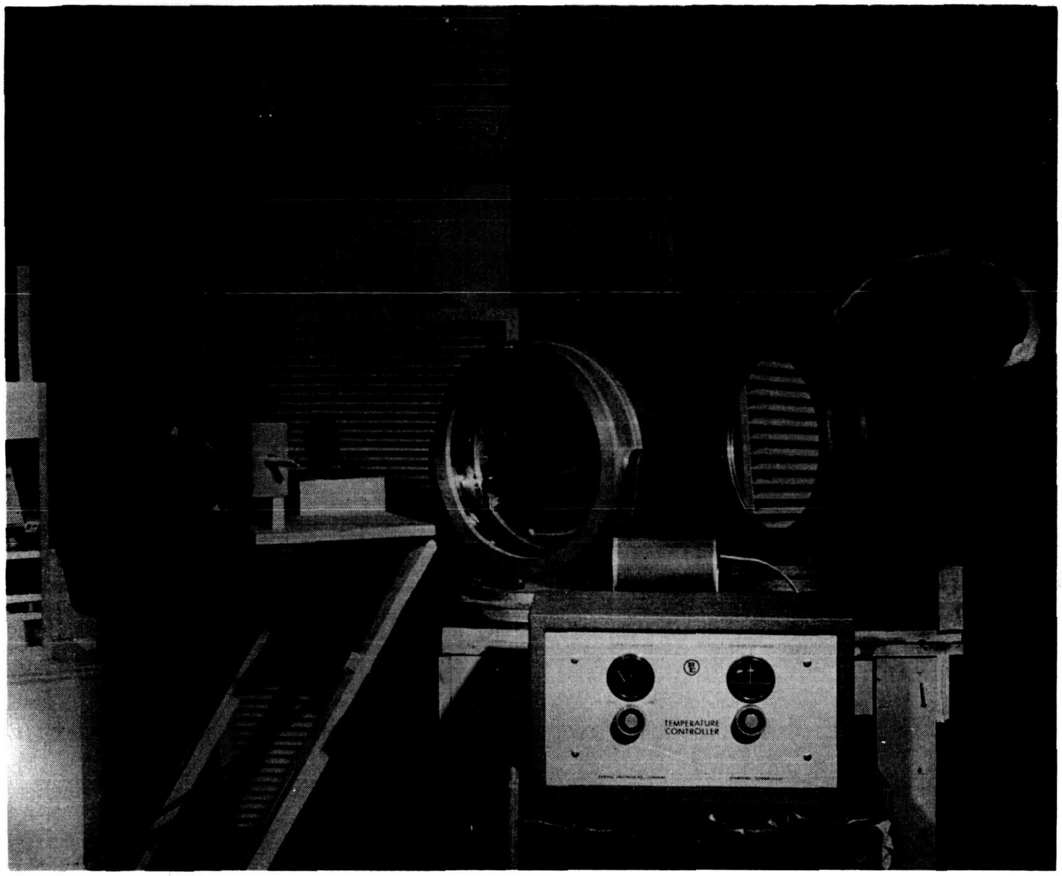

Fig. 2. "The Submillimeter Receiver Coupled to the Coeleostat". Radiation from the two roof-mounted mirrors of the coeleostat (Fig. 1) impinges vertically upon the large 45° plane mirror which can be seen through the doorway into the other room. From there it is reflected to a 12-inch plane mirror (with back to the camera) and thence to a 12-inch spherical mirror of one meter focal length, which brings the radiation to focus on the small aluminum flat which is supported by the ring stand. A chopper is placed between the spherical mirror and the aluminum flat when the aperiodic mode operation is employed. From the aluminum flat the radiation is reflected to a small off-axis parabolic mirror which forms it into a collimated beam 3" in diameter which enters the interferometric receiver at the left of the picture. The unit in the foreground is the control unit for the black body source used for test and allignment.

Fig. 3. "A Typical Spectrum Obtained with the Interferometric Modulator Operating in the Aperiodic Mode".

The source of radiation was a black body source at 225°C, this radiation being first doubly passed through a 0.054 inch thick piece of black polyethelene. The room humidity was 21% at 70°F and an 80 line-per-inch nickel mesh oriented at 90° was used as the beam splitter. This data was obtained by computer processing of the interferometric data.

The rapidly occurring fluctuations are thought to be "channel spectra" caused by optical resonances within the Golay cell. The repeatability of these fine spectra are very good from test to test with different meshes and radiation filters. The coarser variations are due to the radiation curve of the black body source, the efficiency of the beam splitter at different wavelengths and the transmission characteristics of the radiation filters, crystal quartz windows, and the atmosphere.

The 80 LPI mesh is most efficient at long wavelengths and thus this portion of the plot is emphasized more than the shorter wavelengths, while the black polyethelene and crystal quartz filtering causes the region where λ is shorter than 100μ to be heavily attenuated. Some particular features are the dip near 83μ which agrees with a known absorption band of crystal quartz, peaks at 90-95μ, 230μ and 280-370μ which agree with known atmospheric "window", and dips at 160-180μ, 220μ and 230-270μ which agree with known H_2O absorption bands. The resolution of the instrument was such that the width of the main peak was about $2.5\ cm^{-1}$.

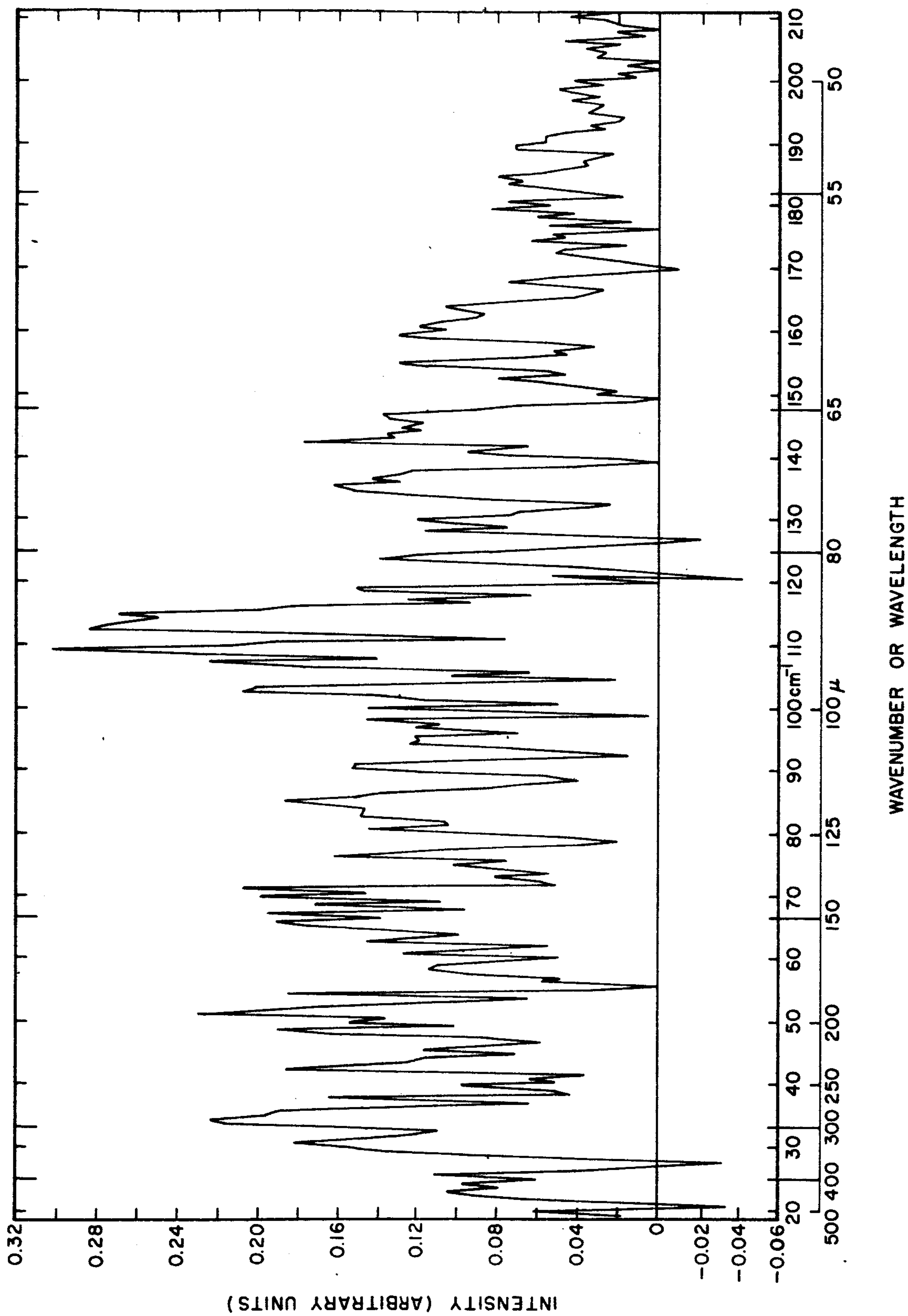
INTENSITY (ARBITRARY UNITS)
WAVENUMBER OR WAVELENGTH
0.32
0.28
0.24
0.20
0.16
0.12
0.08
0.04
0
-0.02
-0.04
-0.06
20 30 40 50 60 70 80 90 100cm⁻¹ 110 120 130 140 150 160 170 180 190 200 210
500 400 300 250 200 150 125 100μ 80 65 55 50

Fig. 3.

The initial data on solar spectra confirmed our previous suspicion that solar spectra cannot be obtained at Columbus, Ohio, because of the large amount of water vapor absorption in the atmosphere. These data also indicate that a less noisy detector than the Golay cell would be desirable for such measurements. The initial test data on the instrument showed that we have two problems to be solved in order to get a perfect instrument. One problem is the "channel spectrum" shown in Fig. 3. This spectrum detracts considerably from the accuracy of the instrument; it seems to be caused by the Golay cell radiation detector. As soon as the Germanium bolometer is delivered (due in March from Texas Instruments, Incorporated), attempts will be made to isolate and to reduce the channel spectra. The second problem concerns the long response time of the Golay detector; the long response time prevents us from operating the instruments in the periodic mode with good results. Again, we are waiting for the bolometer to test the radiometer in its periodic mode in detail. The initial experimental results will be reported later in a separate technical report. This study constitutes a part of the dissertation for Richard A. Williams.

B. The Carbon Bolometer

The carbon bolometer detector mentioned in Report 1093-18 has been operated successfully as a submillimeter detector. Figures 4 and 5 are photographs of this setup. The radiation enters into a tapered light pipe through a black polyethelyne and crystal quartz window. The carbon bolometer is mounted at the end of the light pipe in a vacuum container immersed in liquid helium. The chopped radiation causes a fluctuation of the resistance of the carbon bolometer, which, in turn, give an ac signal to the tuned amplifier through an ac bridge. Figure 6 shows the recorder tracing of the detector output signal when a black body source is placed in front of the light pipe. Although a precise sensitivity test has not yet been made, this detector seems to be insenstivie as compared to the specification of the Texas Instrument germanium bolometers. Experiments are currently being conducted to examine the behavior of this bolometer.

Results of this investigation will be used as part of an M.Sc. thesis.

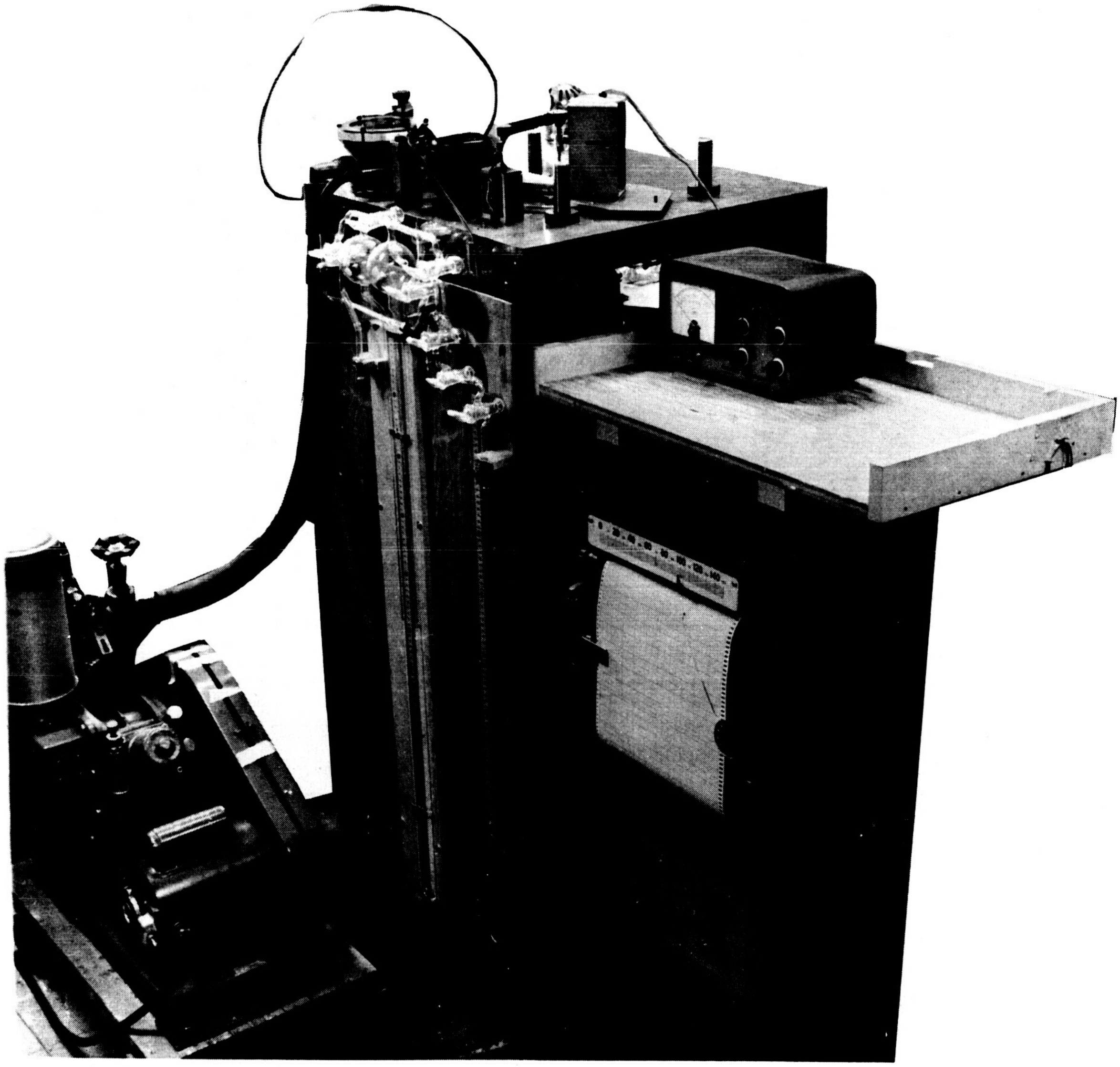

Fig. 4. The carbon bolometer experimental equipment, showing at the left the vacuum pumping and control system which regulates the pressure above the liquid helium bath. At the right is the light pipe pressure monitor, the output recorder, and the black body control unit. On top of the detector box are located the black body source and the radiation chopper, while diffusion and fore pumps for the light pipe are out of sight to the rear.

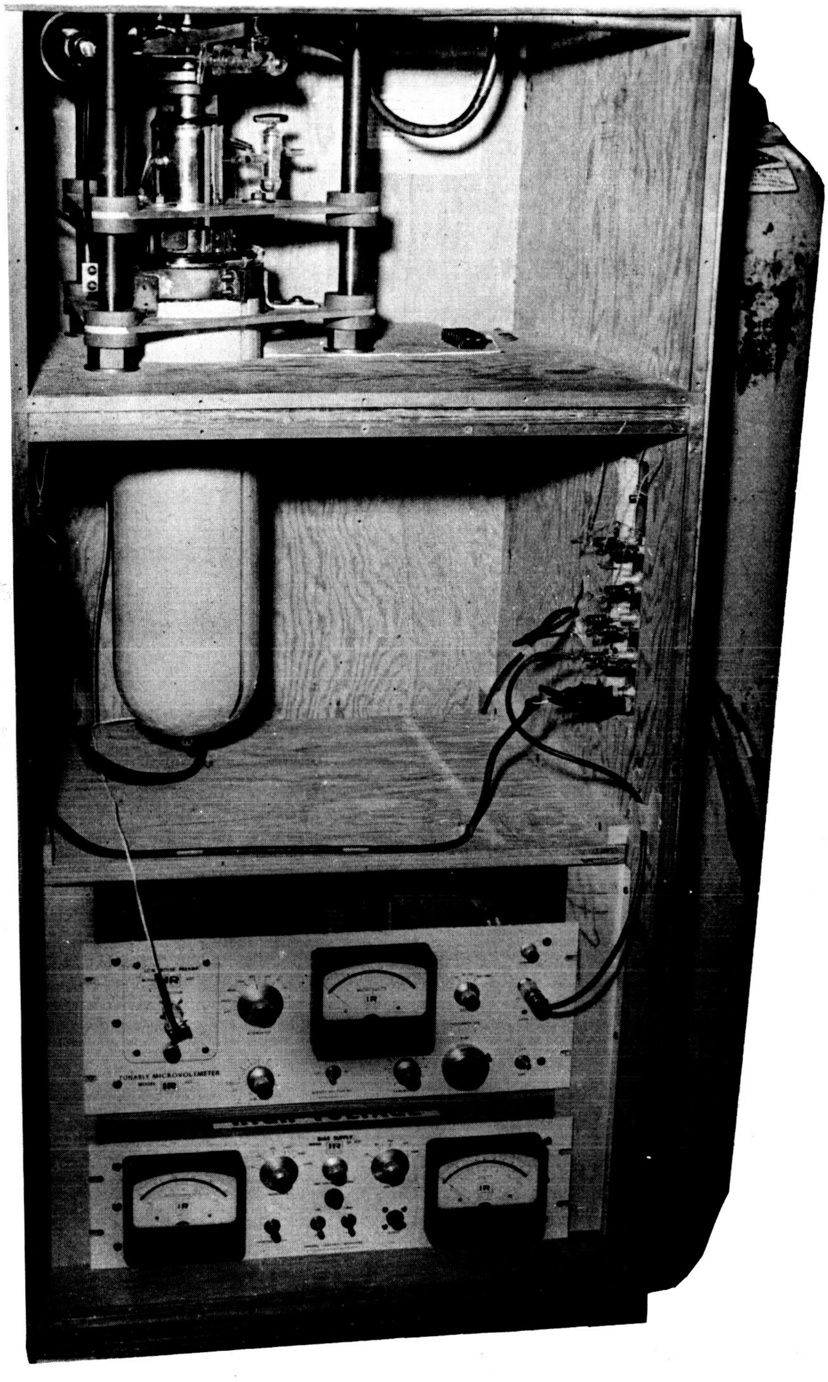

Fig. 5. An interior view of the detector box showing at the top the double dewar arrangement and the various pumping lines, and at the bottom the precision bias supply with the tuned amplifier immediately above it.

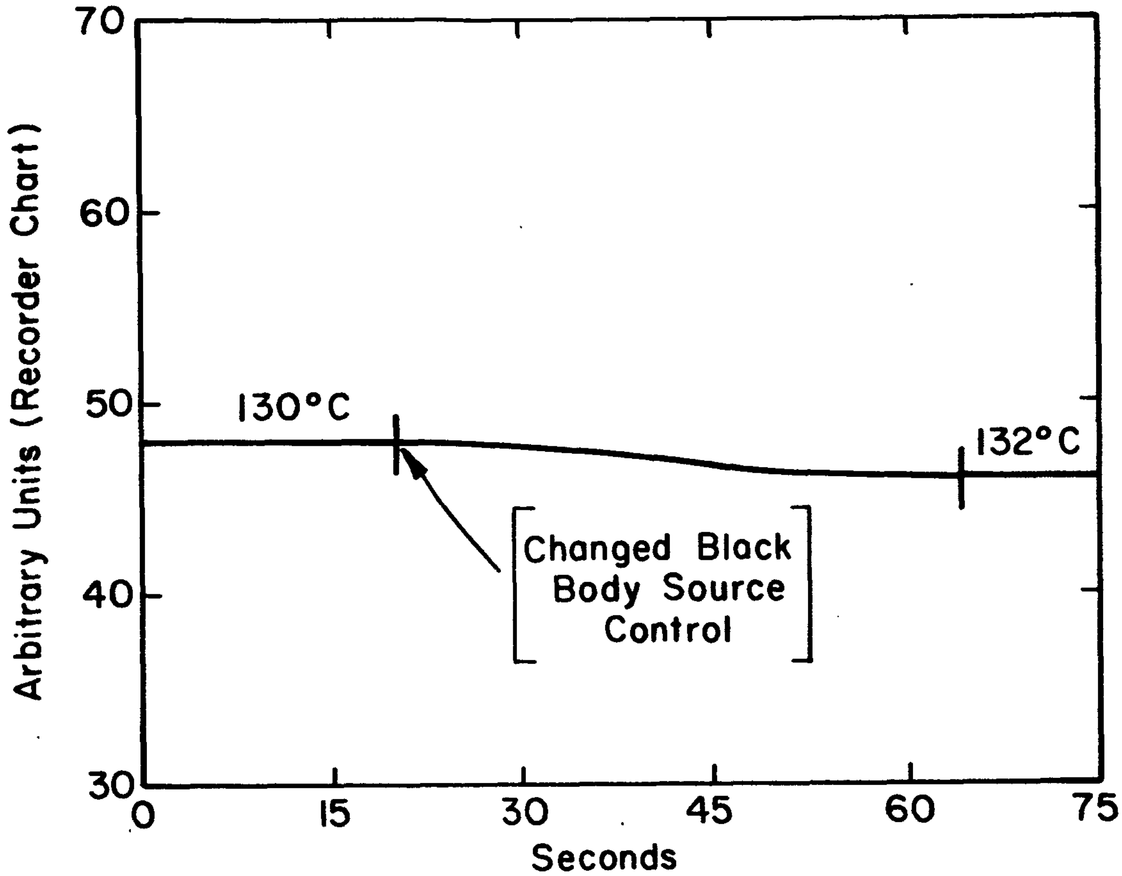

Fig. 6. The recorded response of the carbon bolometer to a change in the black body source temperature. The black body controller was changed from 130°C to 132°C at t = 20 seconds. The slow time response (40 seconds) was due to the lag in the black body source itself.

C. The Submillimeter Maser Material Studies

As reported earlier, in Report 1093-18, we have had trouble with our metallic cryogenic dewar. Subsequently, the dewar was found to have a bad vacuum leak because of the porous material used in its construction. The dewar was completely replaced by the Superior Air Products Company without cost. Since then several successful tests of the dewar have been made with liquid helium. The lowest temperature obtained, as measured by a thermometer on the sample space, was about 5°K without a sample in the sample space. The lowest temperature achieved to date with a sample is 25°K. As soon as lower temperatures can be achieved with the sample and as soon as the Texas Instrument bolometer is available, another attempt will be made to measure the absorption spectra of the rare earth doped laser material at the submillimeter wavelength.

D. Miscellaneous Program

1. The report (1093-17) on the survey of literature on laser materials was completed and distributed in the fall of 1963.

2. Preliminary investigation of the submillimeter radiometer has been published as a paper, entitled "Radiometry of the Submillimeter Region Using the Interferometric Modulator," in the IEEE Transactions, Vol. PTGMTT-11, p. 513, 1963.

3. A paper discussing the experimental aspects of the submillimeter radiometer has been accepted for publication and presentation at the symposium on Quasi-Optics at Brooklyn Polytechnic Institute, New York City, June 8-10, 1964.

4. Preliminary investigation of the parametric interaction produced by the mixing of laser beams to obtain submillimeter radiation has been initiated.

III. RESEARCH PLANS FROM MARCH 1, 1964, TO AUGUST 31, 1964

Basically, we wish to continue our dual program of submillimeter radiometer and submillimeter maser material studies, with emphasis on the radiometer study. Because of the unexpected problems in channel spectra and the poor response time connected with the Golay cell detector, it is estimated that the complete evaluation of the instrument will be accomplished in the summer after the arrival of the Texas Instrument bolometer. On the other hand, since the solar measurement made this winter (1963-64) showed that the atmospheric window at Columbus is too dense to admit any appreciable amount of solar radiation, a high-altitude and low-humidity location must also be found to make our solar radiation measurement.

Through preliminary investigations, we have found three possible sites:

a) the heliostat at the Kitt Peak National Observatory, Arizona;

b) the coeleostat at the Sacramento Peak, New Mexico; or

c) the coeleostat at the High Altitude Laboratory at Climax, Colorado.

More definite arrangements will be made in the spring with one of these observatories, or with any other suitable observatory for making solar measurements in the fall of 1964. Suggestions on the possible use of some NASA facilities would be appreciated.

Experiments with the absorption spectra of the cold rare earth crystals utilizing the more sensitive TI detector are expected to be resumed in the spring. We hope that interesting absorption lines can be observed to give us the information about crystal field splittings and the transition probabilities for maser purposes. The carbon bolometer study will be terminated before August, 1964, and a technical report concerning its results will be prepared. Preliminary investigation of parametric interactions in the millimeter wavelength region will also be continued to prepare for experimental investigations into this area in the late summer or early fall.

IV. FUTURE RESEARCH PLANS FOR THE PERIOD FROM SEPTEMBER 1, 1964 TO AUGUST 31, 1965

If one looks back at the submillimeter and millimeter wave research in the past five years across the entire United States and the world, one finds that these research efforts have made some substantial advances in certain areas but that the total advance has been moderate. This is particularly evident from a comparison of advances made in the submillimeter region and the advances made in the optical region. Considering the tremendous success in optical masers, one naturally wonders whether some of the successful optical quantum electronic techniques could not be brought into the submillimeter wavelength region.

We feel that submillimeter and millimeter research will always be an important scientific tool whether it is for the observation of the sky or for the examination of the properties of materials. However, whether the submillimeter wave would be useful to communications systems on earth or other applications depends a great deal on the water vapor absorption in the atmosphere, which is yet largely unknown. We are fortunate to have a radiometer which can be modified into a spectrometer and to have a long-path absorption cell in which we can simulate the atmosphere at various altitudes (see attached Antenna Laboratory Report 1083-11). Thus we propose that, in the next contract period, we use the radiometer and the long-path absorption cell to determine atmospheric water vapor absorption at various simulated altitudes. This information will be very useful in assessing the usefulness of submillimeter radiation for communications and other applications.

Optical mixing and optical masers are presently extending further and further into the infra-red wavelength. Scientists at the Bell Telephone Laboratories and at the Royal Radar Establishment have already demonstrated laser oscillation at 80μ with a pulsed water vapor laser. Our studies on the possible use of rare earth doped materials follows the same thoughts except that the use of liquid helium complicates the experimental program. On the other hand the mixing from optical masers presents an even more interesting avenue that may eventually bring out many revolutionary devices in millimeter and submillimeter wavelengths. For example, from our preliminary investigations it appears that a millimeter wave signal may be generated by parametric interaction of the axial modes in crystal quartz from a high-power Q-switched laser. By using lasers radiating at slightly different frequencies, and by using nonlinear interactions, these interactions can be generalized to submillimeter and millimeter wavelengths.

In short, we propose that the following study of submillimeter and submillimeter techniques be carried out in the contract period 1964-65:

a) measurement of the water vapor absorption in the atmosphere, and

b) experimentation of the parametric interaction in millimeter wavelengths.

Aside from these two programs, the measurement of the absorption spectra in the solid state materials will be carried out as time permits. Millimeter wave components are already available in the Antenna Laboratory from 4 mm to 8 mm wavelengths. Complete laser laboratory facilities are also available in the Antenna Laboratory.

V. ESTIMATED BUDGET

The program outlined in the preceding sections is obviously a long-range program. Fundamentally, we propose to retain the present engineering manpower effort during subsequent renewal periods, [redacted] Breakdown of a proposed one-year budget is similar to that submitted with our proposal for renewal dated 7 January 1964.